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Composite-composite Adhesion in Dentistry: A Systematic Review and Meta-analysis

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Short Title: Review of studies on composite-composite adhesion

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Purpose: Repair or relayering of aged methacrylate resin-based composites with new composites remains a challenge due to the depletion of free radicals in the aged composite after the initial polymerization. Controversy exists in the literature regarding the most optimal repair procedure for improving the adhesion between the repair resin and the existing resin composite materials. This systematic review analyzed the adhesion potential of resin-based composites to similar and dissimilar composites and aimed to determine the possible dominant factors affecting the bond strength results.

Materials and Methods: Original scientific papers on adhesion to composites published in MEDLINE (PubMed) database between 01/01/1955 and 01/06/2010 were included in this systematic review. The following MeSH terms, search terms and their combinations were used: “Composite Resins”, “Bond Strength”, “Dental Restoration Repair”, “Material testing/methods”, “Repair”. Two reviewers performed screening and data abstraction. Descriptive statistics was performed and the frequencies of the studied parameters, means, standard deviations, Confidence Intervals (95% CI) (uncorrected and corrected) were calculated for the bond strength data reported for different factor levels namely, surface conditioning methods (control, physical, chemical, physico-chemical), substrate-adherent type (being of the same kind or dissimilar), substrate aging (thermocycling or water storage) and test methods (macroshear, microshear, macrotensile, microtensile).

Results: The final search provided 78 titles with abstract. Further abstract screening yielded to 49 articles of which 48 were found potentially appropriate to be included. After abstract reading 1 and full text evaluation, 6 of them were eliminated. The selection process resulted in the final sample of 41 studies. In total, 160 different surface conditioning methods, being mainly combinations of the use of etching agents, application of grinding or air-abrasion

protocols and adhesive promoters (silanes, adhesive resins), have been investigated. The use of three testing methods namely, macroshear, macrotensile and microtensile, was reported. Substrate composites were aged either in water ranging between 8 and 17520 hours or through thermocycling between 300 and 5000 cycles. When substrate is aged with thermocycling, bond strength results for composite-composite combinations of the same material, were significantly influenced by the surface conditioning method ($p = 0.010$) and with the test method ($p = 0.014$) but for dissimilar composite-composite combinations only test method ($p = 0.000$) showed a significant effect on the results. When substrate is aged with water storage, bond strength results for composite-composite combinations of the same material were significantly influenced by the surface conditioning method ($p = 0.000$), but for dissimilar material combinations only test method showed a significant effect ($p = 0.000$) on the results.

Conclusion: Based on the results of this systematic review, for dissimilar substrate-adherend combinations, when substrate is aged either with thermocycling or with water storage, not the surface conditioning method but the test method influences the bond strength results. For the composite combinations of the same kind, the impact of surface conditioning type and the test method in thermocycled group was higher on the results. Adhesion studies on composite-composite adhesion and reporting of data require more standardization.

Key words: adhesion, aging, bond strength, composite resin, dental restoration repair, material testing, relayering, repair, surface conditioning, test method.

INTRODUCTION

Resin-based composites (hereon: composites) are widely used in dentistry since the progress in adhesive technologies. However, failures of composite restorations are still being reported in clinical studies ranging between 5% and 45% during an observation period of 5 to 17 years.[13,28] Failure of a dental composite is often the result of degradation processes taking place within the polymeric matrix and the silanized filler particles of the composite. The degradation processes are complex and could be due to wear, abrasion, fatigue, enzymatic, hydrolytic, acidic or temperature related breakdown.[13,57] When a composite restoration fails as a result of discoloration, micro-leakage, ditching at the margins, delamination or simply due to cohesive fracture, the restoration needs to be repaired or replaced.[5,25,41] Total replacement of the restoration is the most common procedure experienced in daily clinical practice.[45,60,64] However, this approach may be regarded as over-treatment when large portions of the restorations is clinically and radiographically considered free of failures. Moreover, complete removal of a failed restoration would generally entail removal of enamel and/or dentin leading to more loss of sound dental tissues that could inevitably result in weakening of the tooth or injuries to the

pulp.[41] In such cases, repair actions would preserve the tooth as it is often difficult to remove a tooth-colored adhesive restoration without removing an integral part of the tooth.

In general, adhesion between two composite layers is achieved in the presence of an oxygen-inhibited layer of unpolymerized resin.[72] While in previous studies, it was stated that 40-50% of the unreactive methacrylate groups are present after photo-polymerization of the composites that allow for adhesion of new resin layers, unreactive methacrylate groups are reported to be reduced with time, thereby reducing the potential for bonding of resins.[46] Therefore, a great variety of surface conditioning methods and adhesion promoters have been proposed to improve the composite-composite adhesion such as roughening by burs, etching the substrate surface with acidic compounds,[17] air-borne particle abrasion,[23,42,62,72] or using intermediate adhesive resins.[17,18,37] Although promising results were obtained with some of these surface conditioning methods in earlier studies, the tests were often performed on non-aged substrates where the results could be considered optimistic and do not represent the real-life clinical situations. Furthermore, earlier studies were often performed using the same type of composite as both the substrate and the adherend material.[6,21,54-56,58,72] This may not always represent the clinical situation. When a composite restoration fails and the patient has visited several dentists, it is not always possible to trace the information as to which composite material was used and under which conditions it was polymerized. In some occasions, even the restorative composite itself may no longer be launched. For this reason, often in the clinical situation, dissimilar composite materials are adhered to each other during repair.[45] Several studies demonstrated that the composite-composite repair strengths could reach 20-80% of the initial bond strength, depending on the cohesive resistance of the material.[1,22,72] In contrast to the repair of immediately polymerized composites, repair of aged composites represents a challenge due to the depletion of free radicals in the aged composite after the initial polymerization.[5,64]

Even though the literature presents comparative studies, controversy exists regarding to the best surface conditioning method for optimum repair strength of composites. Moreover, aging of the substrate may affect the results. Since the test parameters vary considerably among the available published studies, there is apparent need to develop some guidelines in testing and interpreting the data on adhesion to composites.

The objective of this systematic review therefore was to analyze the adhesion potential of resin-based composites to the composites of the same kind or dissimilar ones and aimed to determine the possible dominant factors affecting the bond strength results.

MATERIALS AND METHODS

Search Strategy

Before the initiation of the literature search, a protocol to be followed was agreed upon by the authors. An electronic search at MEDLINE (PubMed) (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi) from 01/01/1955 and 01/06/2010 was conducted for English-language articles published in the dental literature, using the following MeSH terms, search terms and their combinations: “Composite Resins”, “Bond Strength”, “Dental Restoration Repair”, “Material testing/methods”, “Repair”. The MEDLINE search yielded 78 references to be screened for possible inclusion based on titles and abstracts (Table 1). A further manual search covering the period from 01/01/1955 up to and including 01/06/2010 was performed on the following journals: Journal of Dental Research, Dental Materials, Journal of Adhesive Dentistry, International Journal of Prosthodontics, Journal of Prosthetic Dentistry, Journal of Prosthodontics, and Journal of Biomedical Materials Research Part B: Applied Biomaterials. In addition, hand searches were performed on bibliographies of the selected articles as well as identified narrative reviews to find out

whether the search process has missed any relevant article. This did not add to new additional articles to be involved in the review process.

Inclusion/Exclusion Criteria

In vitro studies reporting on adhesion to composite materials using macroshear, microshear, macrotensile, or microtensile, were included. Publications were excluded if composite was adhered onto tooth substance, data were not presented in MPa and temporary restorations were used. Also, studies performed with pull-out test were not included.

Selection of Studies

Two independent reviewers (B.K-D. and M.Ö.) screened the 78 titles retrieved from the electronic search for possible inclusion in the review. After initial elimination, based on the titles and the abstracts, 48 abstracts were accepted for inclusion by both reviewers. After discussion, a consensus was reached to include 47 articles. Full-text articles were obtained of the 41 selected publications. The two reviewers independently assessed the 41 full-text articles to determine whether they fulfilled the defined criteria for final inclusion. Any disagreement was resolved by discussion. Forty-one studies were found to qualify for inclusion in the review, while 6 articles had to be excluded after full text reading. Process of identifying the studies included in the review from an initial 78 titles is presented in Fig. 1.

Data Extraction

The two reviewers extracted data independently using a data extraction form previously agreed upon. A data collection form containing 37 items was created and used to assess the experimental conditions that may possibly affect the bond strength. Disagreement regarding data extraction was resolved by discussion and a consensus was reached. The variables were recorded and tabulated in Excel sheets. Studies in which data on a certain variable

were lacking or could not be calculated were scored as 'not reported' for the variable in question.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (version 18.0, SPSS Inc, Chicago, IL, USA). The inter-observer agreement with respect to the reporting of experimental conditions of the included abstracts before the consensus meeting is expressed as weighted Cohen's kappa. For descriptive statistics means and standard deviations, or medians and interquartile ranges in skewed distributions were noted. The frequencies of the studied parameters were calculated. Weighted mean values and the 95% confidence interval (CI) for the various outcomes were calculated. Confidence Intervals (95% CI) (uncorrected and corrected) were calculated for mean bond strength for different factor levels, namely for surface conditioning methods (control, physical, chemical, physico-chemical), substrate-adherent type (being of the same kind or dissimilar), substrate aging (thermocycling or water storage) and test methods (macroshear, microshear, macrotensile, microtensile). *P* values smaller than 0.05, were considered to be statistically significant in all comparisons.

RESULTS

Characteristics of the Included/Excluded Studies

The publications qualified for inclusion are presented in Table 2. The Kappa score for agreement between the reviewers for screening of abstracts was 0.85. In the selected 41 articles, [4,6,8-12,19-21,23,27,29,32,34,36,38,44-50, 52-54,58,61,60,63,65-67,70,74-76] a total of 506 experimental subgroups were identified where bond strength results were reported in MPa. In all selected subgroups, the search identified great variety of surface conditioning protocols with 160 different methods to condition composite surfaces prior to composite adhesion (Table 3).

Of the selected 41 articles, substrate aging was more commonly performed using water storage at varying durations (8 to 17520 hours) (n=312 subgroups) than thermocycling (n=84 subgroups) (300-5000 cycles). Physico-chemical conditioning method was more frequently used than physical and chemical conditioning methods. Among test methods, macroshear test was more often used than other test methods. No studies were identified where microshear test was performed. Table 4 shows descriptive statistics on the different parameters tabulated from the selected studies according to the surface conditioning method, aging conditions for the substrate and the test method.

The major findings based on the substrate-adherent combination were as follows:

Adhesion to Composite Substrates Aged with Thermocycling

When substrate is aged with thermocycling, bond strength results for composite-composite combinations of the same material, were significantly influenced by the surface conditioning method ($p = 0.010$) and with the test method ($p = 0.014$) (Table 5a) but for dissimilar composite-composite combinations only test method ($p = 0.000$) showed a significant effect on the results (Table 5b).

Adhesion of composite-composite combinations of the same substrate-adherend composite materials benefitted similarly from all types of conditioning methods. Compared to microtensile test method, macroshear ($p = 0.000$) and macrotensile ($p = 0.025$) tests showed significantly lower results. In the macroshear test, non-thermocycled group showed significantly higher results ($p = 0.001$) compared to thermocycled group (Table 6a).

Adhesion of composite-composite combinations of dissimilar substrate-adherend composite materials also benefitted similarly from all types of conditioning methods. Compared to mictotensile test method, macroshear ($p = 0.004$) and macrotensile ($p = 0.001$) tests showed significantly lower results. Thermocycling significantly decreased the results for the bond strength of dissimilar substrate-adherend composite combinations ($p = 0.013$).

Physical surface conditioning showed significantly higher results for macroshear ($p = 0.012$) than macrotensile test method. Chemical surface conditioning in macroshear test, showed significantly lower ($p = 0.006$) results compared to microtensile test (Table 6b).

Adhesion to Composite Substrates Aged with Water Storage

When substrate is aged with water storage, bond strength results for composite-composite combinations of the same material were significantly influenced by the surface conditioning method ($p = 0.000$), but for dissimilar material combinations only test method showed a significant effect ($p = 0.000$) on the results (Tables 7a-b).

Adhesion of composite-composite combinations of the same material showed significantly lower results in non-conditioned ($p = 0.039$) and chemically conditioned ($p = 0.000$) groups compared to physical and physicochemical conditioning. Macroshear ($p = 0.000$) and macrotensile ($p = 0.010$) tests presented significantly higher results compared to microtensile test (Table 8a). Water storage ($p = 0.008$) significantly decreased the results compared to non-water stored groups. Chemical surface conditioning method in the macroshear test showed significantly lower results ($p = 0.042$) compared to chemical conditioning in microtensile test. Using macroshear test, non-aged control groups presented significantly ($p = 0.000$) higher results compared to aged conditions.

Adhesion of composite-composite combinations of dissimilar materials, using physical conditioning method showed significantly lower results ($p = 0.022$) than physicochemical conditioning (Table 8b). Macroshear ($p = 0.002$) and macrotensile tests ($p = 0.002$) showed significantly lower results than with microtensile test. Water storage did not significantly ($p = 0.156$) affect the results compared to non-water stored groups. Physical surface conditioning in macroshear test showed significantly lower results ($p = 0.005$) compared to macrotensile test. Chemical conditioning in macroshear test presented significantly lower bond strength results compared to microtensile test ($p = 0.002$).

DISCUSSION

Repair or relayering of composite materials is an integral part of dynamic treatment concept and serves for maintenance of such restorations without sacrificing from dental tissues during replacement actions. Composite materials need to be repaired either at early or late phases after their placement. Due to lack of experience with the specific material, inadequate shade selection or mismatch between the restored and the adjacent teeth can be corrected by relayering procedures. In this case, the composite materials are not aged and therefore adding a new layer of composite onto an existing, already polymerized composite does not present much of a problem during layering in the same session and could be considered as early repairs.[39] On the other hand, degradation of the composite surfaces that could be considered as a multifactorial clinical problem could result in aging of the material. Although clinicians spend 70% of their chairside time replacing restorations,[41] with the introduction of adhesive technologies, the service life of even such restorations could be prolonged. When composite is polymerized under the air, an oxygen-inhibited layer is always present. This layer contains unreacted acrylate groups which improve adhesion between the substrate and the second layer by the formation of covalent bonds.[35,64,68,69] In fact, in aged conditions, active free radicals may be expected to be less. Since both early and late repair actions are of clinical interest for the aim of reducing the restoration cycle, mainly due to variations in testing environments, no consensus has been established in recommending the best repair protocol for early and late repairs. Hence, this systematic review aimed for analyzing the published literature in the field of composite repairs in dentistry and make suggestions for future investigations.

Typically the composite materials used in dental applications are based on methacrylate resins. While different aging procedures have been tried in the dental literature, in this review only thermocycling and water storage have been considered as aging regimens. Despite the fact that water storage simulates aging due to water uptake only, thermocycling represents hydrothermal aging. Temperature changes and repetitive contraction-expansion stresses that occur in the composite materials could have a significant impact on the adhesion of the subsequent composite layer. In the selected studies, water storage hours showed a big variation between 8 and 17520 hours corresponding to 0.33 and 730 days, respectively. Water sorption level of composites certainly varies depending on their filler content in relation to the methacrylate monomer matrix and after a certain point saturation could be expected. In that respect, almost 2 years of water storage has undoubtedly a different effect than storage for less than a day. Variations in standard deviations could easily be attributed to this factor. Nevertheless, statistical analysis indicated that water storage did not significantly affect the results compared to non-water stored groups. In that respect, aging with thermocycling demonstrated more detrimental effect on the bond strength results.

Since thermocycling could be considered to represent worse case aging scenario, the data extraction was performed only from non-thermocycled (dry stored) and thermocycled groups. The number of cycling also for thermocycling groups showed a big variation ranging between 300 and 5000 cycles. Similar to water storage groups, the results presented here showed high standard deviations. According to the ISO norm 10477,[33] minimum number of thermocycling was proposed as 5000 cycles to assess metal-resin bond. To the authors` best knowledge, such a standard does not exist for aging composite materials or for aging composite-composite adhesion. Therefore, some standardization on the aging protocols for composite materials seems to be crucial. The frequency of cycles in vivo remains to be

determined at present and requires formal estimation. On the basis that such cycles might occur between 20 and 50 times a day, it is proposed that 10.000 cycles might represent one year of in vivo functioning.[17,24] Based on the evaluated studies, aging composites in water storage (n=312 subgroups) was a more common practice compared to thermocycling (n=84 subgroups). This may relate to the availability of this device where the studies were conducted. Nonetheless, when substrate composite was aged either with thermocycling or with water storage and bonded with the same composite material, surface conditioning methods and in particular physicochemical conditioning methods showed a significant impact on the bond strength results.

In the selected 41 articles, a total of 506 experimental subgroups were identified with a great variety of surface conditioning protocols, namely 160 different methods were used to condition the composite surfaces prior to adhering the subsequent composite material. Physico-chemical conditioning method was more frequently used than physical and chemical conditioning methods. The prerequisite for effective adhesion of polymeric materials onto any substance is to achieve a clean surface free of contaminants. In previous studies, the success of composite-to-composite adhesion was reported to depend on the chemical composition of the surface, its roughness, wettability, and the surface conditioning procedures applied.[3,7,30,31,44,69] In the reviewed articles, while in the majority of the studies composite surfaces were typically grinded with silicone carbide abrasive papers ranging between 60 and 1200-grit, others started with cleaning the surfaces using etching solutions. In fact, surface conditioning takes place already with the grinding processes and the starting surface roughness may have an impact on the results.

Since a great plethora of conditioning methods were noted, in this review they were categorized in four groups only. The particle deposition techniques or the use of burs were considered as physical conditioning methods. The abrasives used were often Al_2O_3 or SiO_2

particles with particle size ranging between 25 and 50 μm. Air-abrasion methods clean the surface and increase the surface energy. The pressure and duration of the deposition are important parameters to consider in achieving an optimal roughness.[43] The results in general indicated that physico-chemical conditioning methods regardless of such air-abrasion related parameters tend to increase the bond strength values for composites. Yet, the results of this review based on the available data indicated that compared to the control groups where no conditioning was practiced, physical conditioning with air-abrasion seems to increase the composite-composite bond strength.

Several testing methodologies such as macroshear, microshear, macrotensile, and microtensile tests have been suggested for evaluation of the bond strength of resin-based materials to different substrates in dentistry. It is critical that the bonding interface should be the most stressed region, regardless of the test methodology being employed. Previous studies using stress distribution analyses have reported that some bond strength tests do not appropriately stress the interfacial zone.[14-16,73] Shear tests have been criticized for the development of non-homogeneous stress distributions in the bonded interface, inducing either underestimation or misinterpretation of the results, as the failure often starts in one of the substrates and not at the adhesive zone.[14,15,73] Although conventional tensile tests also present some limitations, such as the difficulty of specimen alignment, this type of test was proposed to provide information on global bond strength.[14] Microtensile test allows better alignment of the specimens, and a more homogeneous distribution of stress, in addition to a more sensitive comparison or evaluation of bond performances.[2] This systematic review indicated that against the limitations of shear tests, macroshear test continues to be more commonly applied. No studies were identified where microshear test was performed. Particularly for dissimilar composite-composite combinations, test method had a significant effect on the bond strength results both in thermocycled or water stored groups. The highest

bond strength results were obtained from microtensile tests followed by macroshear and macrotensile tests in both thermocycled and water-aged groups. In the macro shear test, for both composite-composite combinations of similar and dissimilar composites non-thermocycled group showed significantly higher results compared to thermocycled group, clearly indicating the aging effect of thermocycling. Although initially intended, failure type analysis could not be classified in this review due to inconsistency.

Clinically sufficient bond strength value is not known for composite-composite adhesion. The great variation in testing parameters and testing environment would continue to create the confusion in the dental literature. Since in the future new studies are expected to appear in this field, the following points could be suggested:

- The steps of conditioning methods should be defined precisely.
- A consensus needs to be made on aging parameters.
- Exact composition of the composites should be given.
- Composite-composite bond strength should be verified with different test methods in one study.
- The bond strength data should be presented with confidence intervals, mean, minimum and maximum values.
- Failure types after bond tests should be listed in detail.

CONCLUSIONS

From this review, the following could be concluded:

1. Current studies regarding the composite-composite adhesion should be evaluated cautiously considering the surface conditioning method, aging conditions of the substrate composite and the employed test method. Some more systematic approach especially regarding to aging conditions is needed when studying adhesion to composites.

2. Future adhesion studies to composites should implement a non-conditioned control group with exact definition of the conditioning protocol.

3. For dissimilar substrate-adherend combinations, when substrate is aged either with thermocycling or with water storage, the surface conditioning method seems to be insignificant but the test method influences the bond strength results.

4. For the composite combinations of the same kind, the impact of surface conditioning type was more significant.

5. Surface conditioning methods and in particular physico-chemical conditioning methods, increased the composite-composite bond strength.

Clinical relevance:

For durable repair or relayering of aged composites, physico-chemical surface conditioning of the substrate composite seems to be essential.

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51. Papacchini F, Toledano M, Monticelli F, Osorio R, Radovic I, Polimeni A, García-Godoy F, Ferrari M. Hydrolytic stability of composite repair bond. Eur J Oral Sci 2007;115:417-424.

52. Perriard J, Lorente MC, Scherrer S, Belser UC, Wiskott HW. The effect of water storage, elapsed time and contaminants on the bond strength and interfacial polymerization of a nanohybrid composite. J Adhes Dent 2009;11:469-478.

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66. Tezvergil A, Lassila LV, Vallittu PK. Composite-composite repair bond strength: effect of different adhesion primers. J Dent 2003;31:521-525.

67. Tezvergil A, Lassila LV, Yli-Urpo A, Vallittu PK. Repair bond strength of restorative resin composite applied to fiber-reinforced composite substrate. Acta Odontol Scand 2004;62:51-60.

68. Tezvergil A, Lassila LV, Vallittu PK. Composite-composite repair bond strength: effect of different microfine hybrid restorative composite using nontrimmed hourglass specimens. J Adhes Dent 2009;11:41-7.

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76. Yesilyurt C, Kusgoz A, Bayram M, Ulker M. Initial repair bond strength of a nano-filled hybrid resin: effect of surface treatments and bonding agents. J Esthet Restor Dent 2009;21:251-260.

Captions to tables and figures:

Tables

Table 1. Search strategy in MEDLINE applied for this review. #: search, MeSH: Medical subjects heading, a thesaurus word.

Table 2. Articles selected for the review that met the inclusion criteria.

Table 3. Sequence of surface conditioning methods used for composite resins as stated by the authors.

Table 4. Descriptive statistics on the different parameters tabulated from the selected studies according to the surface conditioning methods, aging conditions for the substrate and the test method.

Tables 5a-b. Significant effects of surface conditioning methods, test methods and their interactions on mean bond strengths for thermocycled groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Tables 6a-b. Significant differences for cross-comparisons and interactions between surface conditioning methods, test methods for thermocycled groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Tables 7a-b. Significant effects of surface conditioning methods, test methods and their interactions on mean bond strengths for water stored groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Tables 8a-b. Significant differences for cross-comparisons and interactions between surface conditioning methods, test methods for water stored groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Figures

Fig. 1 Process of identifying the studies included in the review.

Figs. 2a-f Mean bond strength (MPa) for substrate-adherent adhesion of the same kind (Substrate=Adherent) with and without thermocycling of the substrate after macroshear, macrotensile and microtensile tests.

Figs. 3a-f Mean bond strength (MPa) for substrate-adherent adhesion of dissimilar composites (Substrate≠Adherent) with and without thermocycling of the substrate after macroshear, macrotensile and microtensile tests.

Figs. 4a-f Mean bond strength (MPa) for substrate-adherent adhesion of the same kind (Substrate=Adherent) with and without water storage of the substrate after macroshear, macrotensile and microtensile tests.

Figs. 5a-f Mean bond strength (MPa) for substrate-adherent adhesion of dissimilar composites (Substrate≠Adherent) with and without water storage of the substrate after macroshear, macrotensile and microtensile tests.

Legends

Tables:

Table 1. Search strategy in MEDLINE applied for this review. #: search, MeSH: Medical subjects heading, a thesaurus word.

Search	Literature search strategy	Results
1	“Composite Resins” [MeSH]	19753
2	“Composite Resins”	386
3	“Bond Strength”	206
4	“Dental Restoration Repair” [MeSH]	0
5	“Repair”	0
6	“Material Testing/Methods” [MeSH]	3849
7	(“1995/01/01”[Publication Date]: “2010/06/01” ”[Publication Date]) AND ((((((#1) AND #2) AND #3) AND #6)	78

Table 2 Articles selected for the review that met the inclusion criteria.

Number	Source listed chronologically
1	Puckett AD, Holder R, O'Hara JW. Strength of posterior composite repairs using different composite/bonding agent combinations. Oper Dent 1991;16:136-40.
2	Gregory WA, Berry S, Duke E, Dennison JB. Physical properties and repair bond strength of direct and indirect composite resins. J Prosthet Dent 1992;68:406-411.
3	Shiau JY, Rasmussen ST, Phelps AE, Enlow DH, Wolf GR. Analysis of the shear bond strength of pretreated aged composites used in some indirect bonding techniques. J Dent Res 1993;72:1291-1297.
4	Flores S, Charlton DG, Evans DB. Repairability of polyacid-modified composite resin. Oper Dent 1995;20:191-196.
5	Brosh T, Pilo R, Bichacho N, Blutstein R. Effect of combinations of surface treatments and bonding agents on the bond strength of repaired composites. J Prosthet Dent 1997;77:122-126.
6	Bouschlicher MR, Reinhardt JW, Vargas MA. Surface treatment techniques for resin composite repair. Am J Dent 1997;10:279-283.
7	Lewis G, Johnson W, Martin W, Canerdy A, Claburn C, Collier M. Shear bond strength of immediately repaired light-cured composite resin restorations. Oper Dent 1998;23:121-127.
8	Shahdad SA, Kennedy JG. Bond strength of repaired anterior composite resins: an in vitro study. J Dent 1998;26:685-694.
9	Sau CW, Oh GS, Koh H, Chee CS, Lim CC. Shear bond strength of repaired composite resins using a hybrid composite resin. Oper Dent 1999;24:156-161.
10	Yap AU, Sau CW, Lye KW. Effects of aging on repair bond strengths of a polyacid-modified composite resin. Oper Dent 1999;24:371-376.
11	Kallio TT, Lastumäki TM, Vallittu PK. Bonding of restorative and veneering composite resin to some polymeric composites. Dent Mater 2001;17:80-86.
12	Lucena-Martín C, González-López S, Navajas-Rodríguez de Mondelo JM. The effect of various surface treatments and bonding agents on the repaired strength of heat-treated composites. J Prosthet Dent 2001;86:481-488.
13	Hisamatsu N, Atsuta M, Matsumura H. Effect of silane primers and unfilled resin bonding agents on repair bond strength of a prosthodontic microfilled composite. J Oral Rehabil 2002;29:644-648.
14	Frankenberger R, Krämer N, Ebert J, Lohbauer U, Käppel S, ten Weges S, Petschelt A. Fatigue behavior of the resin-resin bond of partially replaced resin-based composite restorations. Am J Dent 2003;16:17-22.
15	Oztas N, Alacam A, Bardakçi Y. The effect of air abrasion with two new bonding agents on composite repair. Oper Dent 2003;28:149-154.
16	Tezvergil A, Lassila LV, Vallittu PK. Composite-composite repair bond strength: effect of different adhesion primers. J Dent 2003;31:521-525.
17	Tezvergil A, Lassila LV, Yli-Urpo A, Vallittu PK. Repair bond strength of restorative resin composite applied to fiber-reinforced composite substrate. Acta Odontol Scand 2004;62:51-60.
18	Trajtenberg CP, Powers JM. Effect of hydrofluoric acid on repair bond strength of a laboratory composite. Am J Dent 2004;17:173-176.
19	Hisamatsu N, Tanoue N, Yanagida H, Atsuta M, Matsumura H. Twenty-four hour bond strength between

	layers of a highly loaded indirect composite. Dent Mater J 2005;24:440-446.
20	Özcan M, Alander P, Vallittu PK, Huysmans MC, Kalk W. Effect of three surface conditioning methods to improve bond strength of particulate filler resin composites. J Mater Sci Mater Med 2005;16:21-27.
21	Teixeira EC, Bayne SC, Thompson JY, Ritter AV, Swift EJ. Shear bond strength of self-etching bonding systems in combination with various composites used for repairing aged composites. J Adhes Dent 2005;7:159-164.
22	Hannig C, Laubach S, Hahn P, Attin T. Shear bond strength of repaired adhesive filling materials using different repair procedures. J Adhes Dent 2006;8:35-40.
23	Brendeke J, Özcan M. Effect of physicochemical aging conditions on the composite-composite repair bond strength. J Adhes Dent 2007;9:399-406.
24	Dall'Oca S, Papacchini F, Goracci C, Cury AH, Suh BI, Tay FR, Polimeni A, Ferrari M. Effect of oxygen inhibition on composite repair strength over time. J Biomed Mater Res B Appl Biomater 2007;81:493-498.
25	Lassila LV, Tezvergil A, Dyer SR, Vallittu PK. The bond strength of particulate-filler composite to differently oriented fiber-reinforced composite substrate. J Prosthodont 2007;16:10-17.
26	Özcan M, Barbosa SH, Melo RM, Galhano GA, Bottino MA. Effect of surface conditioning methods on the microtensile bond strength of resin composite to composite after aging conditions. Dent Mater 2007;23:1276-1282.
27	Papacchini F, Dall'Oca S, Chieffi N, Goracci C, Sadek FT, Suh BI, Tay FR, Ferrari M. Composite-to-composite microtensile bond strength in the repair of a microfilled hybrid resin: effect of surface treatment and oxygen inhibition. J Adhes Dent 2007;9:25-31.
28	Papacchini F, Monticelli F, Hasa I, Radovic I, Fabianelli A, Polimeni A, Ferrari M. Effect of air-drying temperature on the effectiveness of silane primers and coupling blends in the repair of a microhybrid resin composite. J Adhes Dent 2007;9:391-397.
29	Papacchini F, Monticelli F, Radovic I, Chieffi N, Goracci C, Tay FR, Polimeni A, Ferrari M. The application of hydrogen peroxide in composite repair. J Biomed Mater Res B Appl Biomater 2007;82:298-304.
30	Papacchini F, Toledano M, Monticelli F, Osorio R, Radovic I, Polimeni A, García-Godoy F, Ferrari M. Hydrolytic stability of composite repair bond. Eur J Oral Sci 2007;115:417-424.
31	Chen HL, Lai YL, Chou IC, Hu CJ, Lee SY. Shear bond strength of provisional restoration materials repaired with light-cured resins. Oper Dent 2008;33:508-515.
32	Dall'oca S, Papacchini F, Radovic I, Polimeni A, Ferrari M. Repair potential of a laboratory-processed nano-hybrid resin composite. J Oral Sci 2008;50:403-412.
33	Fawzy AS, El-Askary FS, Amer MA. Effect of surface treatments on the tensile bond strength of repaired water-aged anterior restorative micro-fine hybrid resin composite. J Dent 2008;36:969-976.
34	Papacchini F, Radovic I, Magni E, Goracci C, Monticelli F, Chieffi N, Polimeni A, Ferrari M. Flowable composites as intermediate agents without adhesive application in resin composite repair. Am J Dent 2008;21:53-58.
35	Souza EM, Francischone CE, Powers JM, Rached RN, Vieira S. Effect of different surface treatments on the repair bond strength of indirect composites. Am J Dent 2008;21:93-96.
36	El-Askary FS, Fawzy AS, Abd Elmohsen HM. Tensile bond strength of immediately repaired anterior microfine hybrid restorative composite using nontrimmed hourglass specimens. J Adhes Dent 2009;11:41-47.
37	Perriard J, Lorente MC, Scherrer S, Belser UC, Wiskott HW. The effect of water storage, elapsed time and

	contaminants on the bond strength and interfacial polymerization of a nanohybrid composite. J Adhes Dent 2009;11:469-478.
38	Vivas J, Yaman P, Taylor G. Effect of different surface treatments on the shear and flexural re-bond strengths of a micro-hybrid composite. J Contemp Dent Pract 2009;10:E001-8.
39	Yesilyurt C, Kusgoz A, Bayram M, Ulker M. Initial repair bond strength of a nano-filled hybrid resin: effect of surface treatments and bonding agents. J Esthet Restor Dent 2009;21:251-260.
40	Costa TR, Ferreira SQ, Klein-Júnior CA, Loguercio AD, Reis A. Durability of surface treatments and intermediate agents used for repair of a polished composite. Oper Dent 2010;35:231-237.
41	Rinastiti M, Özcan M, Siswomihardjo W, Busscher HJ. Immediate repair bond strengths of microhybrid, nanohybrid and nanofilled composites after different surface treatments. J Dent 2010;38:29-38.

Table 3. Sequence of surface conditioning methods used for composite resins as stated by the authors.

Surface Conditioning Methods
14 d air aging+Grinding 400grit
Abraded Sof-Lex disk
Abraded with diamond fissure bar
Abraded with diamond fissure bar+Bonding
Abrasion corse Al2O3 disk+cleaning with 37% H3PO4 (60s)+Bonding
Air Abrasion 50μm Al2O3+Etching 37% H3PO4 (15s)+Bonding
Air Abrasion 50μm Al2O3+Etching 37% H3PO4 (60s)+Bonding
Air-abraded 50μm Al2O3+Etching 35% PA (30s)+Bonding
Air-inhibition
Air-steam+50μm Al2O3+Bonding
Air-steam+50μm Al2O3+Silanization+Bonding
Bonding
Cleaning 37% H3PO4 (30s)+Bonding
CoJet 30μm SiOx+Silanization
Cojet Silica coating 30μm Al2O3+Etching 37% H3PO4 (30s)+Bonding
Co-Jet+Silanization
Diamond Bur 150μm+Bonding
Diamond bur fine grit+Bonding+light curing in air-atmosphere
Diamond bur fine grit+Bonding+light curing in nitrogen-atmosphere
Diamond bur fine grit+Etching 37% H3PO4(30s)+Bonding+light curing in air-atmosphere
Diamond bur fine grit+Etching 37% H3PO4(30s)+Bonding+light curing in nitrogen-atmosphere
Diamond bur medium grit+Cleaning 37% H3PO4 (30s)+Bonding
Etching >10% HCL&6.9%HF (60s)+Bonding+light curing in air-atmosphere
Etching >10% HCL&6.9%HF (60s)+Bonding+light curing in nitrogen-atmosphere
Etching 35% PA (30s)+Bonding
Etching 37% H3PO4 (15s)+9.6% HF (120s)+Bonding
Etching 37% H3PO4 (15s)+99% acetone (60s)+Bonding
Etching 37% H3PO4 (15s)+Bonding
Etching 37% H3PO4 (15s)+Silanization+Bonding
Etching 37% H3PO4 (15s)+with polyester strip+Bonding
Etching 37% H3PO4 (30s)+Bonding
Etching 37% H3PO4 (60s)+Bonding
Etching 37% PA (5min)
Etching 38% H2O2+Bonding
Etching 38% H2O2+Silanization+Bonding
Etching 38% PA (60s)+Bonding
Etching 9.5% Hydrophloric Acid (60s)
Etching 9.5% Hydrophloric Acid (60s)+Bonding
Etching 9.5% Hydrophloric Acid (60s)+Silanisation
Etching 9.6% HF (120s)+Bonding
Etching 9.6% HF (60s)+Bonding

Finishing Diamond bur 40grit+cleaning in ethanol 10s

Grinding (120+320+600)grit+Air-Abrasion 50μm Al2O3

Grinding (120+320+600)grit+Etching 8% HF (15s)+immersion NaOH (5min)+Silanization+Bonding

Grinding (120+320+600)grit+Etching 8% HF (15s)+Silanization+Bonding

Grinding (60+120+320+600)grit+Etching 5% HF (10s)

Grinding (60+120+320+600)grit+Etching 5% HF (15s)

Grinding (60+120+320+600)grit+Etching 5% HF (30s)

Grinding (60+120+320+600)grit+Etching 5% HF (5s)

Grinding (60+120+320+600)grit+Etching 5% HF (60s)

Grinding (60+120+320+600)grit+Etching 8% HF (10s)

Grinding (60+120+320+600)grit+Etching 8% HF (15s)

Grinding (60+120+320+600)grit+Etching 8% HF (30s)

Grinding (60+120+320+600)grit+Etching 8% HF (5s)

Grinding (60+120+320+600)grit+Etching 8% HF (60s)

Grinding (60+120+320+600)grit+Etching 9.5% HF (10s)

Grinding (60+120+320+600)grit+Etching 9.5% HF (15s)

Grinding (60+120+320+600)grit+Etching 9.5% HF (30s)

Grinding (60+120+320+600)grit+Etching 9.5% HF (5s)

Grinding (60+120+320+600)grit+Etching 9.5% HF (60s)

Grinding 1200grit+Bonding

Grinding 1200grit+US cleaning in distilled water (10min)+Air-borne Abrasion 50μm Al2O3+Silanization+Bonding

Grinding 1200grit+US cleaning in distilled water (10min)+Cojet Silica coating 30μm SiO2+Silanization

Grinding 1200grit+US cleaning in distilled water (10min)+Cojet Silica coating 30μm SiO2+Silanization+Bonding

Grinding 1200grit+US cleaning in distilled water (10min)+Etching 35% H3PO4(60s)+Bonding

Grinding 1200grit+US cleaning in distilled water (10min)+Etching 9.5% HF (90s)+Silanization+Bonding

Grinding 1200grit+US cleaning in distilled water (15min)

Grinding 1200grit+US cleaning in distilled water (15min)+Bonding

Grinding 180grit+US cleaning in distilled water

Grinding 180grit+US cleaning in distilled water+Bonding

Grinding 320grit

Grinding 320grit+Etching (10% maleic acid 20s)+Bonding

Grinding 320grit+Etching (10% polyacrylic acid 20s)+Bonding

Grinding 320grit+Sandblasting 50μm Al2O3+Bonding

Grinding 400grit

Grinding 400grit+Bonding

Grinding 400grit+dipped in blood 15s

Grinding 400grit+dipped in fresh saliva 15s

Grinding 400grit+Grinding 240grit+Bonding

Grinding 400grit+Silanization

Grinding 400grit+Silanization+Bonding

Grinding 500grit+Air-abrasion 25μm Al2O3+Cleaning 37% H3PO4(10s)

Grinding 500grit+Air-abrasion 25μm Al2O3+Cleaning 37% H3PO4(10s)+Bonding

Grinding 500grit+Sanded+500grit Al2O3+Cleaning 37% H3PO4(10s)

Grinding 500grit+Sanded+500grit Al2O3+Cleaning 37% H3PO4(10s)+Bonding

Grinding 5x (150grit+360grit+600grit+1200grit)+Bonding
Grinding 5x(150grit+360grit+600grit+1200grit)+Diamond bur+Cleaning 35% H3PO4 (30s)+Bonding
Grinding 5x(150grit+360grit+600grit+1200grit)+Sandblasting 50µm Al2O3+Cleaning 35% H3PO4 (30s)+Bonding
Grinding 600grit Soflex Disk+Etching 35% H3PO4(15s)+Bonding
Grinding 600grit+Bonding
Grinding 800grit+Etching H3PO4 (60s)+Bonding
Grinding 800grit+Etching H3PO4 (60s)+Co-Jet+Silanization
Grinding 800grit+Etching H3PO4 (60s)+Co-Jet+Silanization+Bonding
Grinding 800grit+Etching H3PO4 (60s)+Silanization
Grinding 800grit+Etching H3PO4 (60s)+Silanization+Bonding
Grinding abrasive stone+Bonding
Grinding abrasive stone+Etching 37% H3PO4 (15s)+Bonding
Grinding abrasive stone+Etching 37% H3PO4 (15s)+with polyester strip+Bonding
Grinding abrasive stone+Silanization+Bonding
Grinding abrasive stone+Silanization+Etching 37% H3PO4 (15s)+Bonding
Grinding abrasive stone+with polyester strip+Bonding
Grinding blasted 50µm Alumina
Grinding blasted 50µm Alumina+Etching 37% PA (5min)
Grinding diamondstone
Grinding diamondstone+Bonding
Grinding diamondstone+Silanisation
Grinding fluted carbide bur
Grinding Green Carborundum stone
Grinding Green Carborundum stone+Bonding
Grinding Green Carborundum stone+Silanisation
Hand-polished 320grit silicon carbide+US cleaning 3min+abraded 4s with 27µm Al2O3 (KCP-2000)+32% H3PO4 15s
Hand-polished 320grit silicon carbide+US cleaning 3min+abraded 4s with 27µm Al2O3 (KCP-2000)+32% H3PO4 15s+Silanizati
Hand-polished 320grit silicon carbide+US cleaning 3min+abraded 4s with 50µm Al2O3 (microetcher)+32% H3PO4 15s
Hand-polished 320grit silicon carbide+US cleaning 3min+abraded 4s with 50µm Al2O3 (microetcher)+32% H3PO4 15s+Silaniza
Hand-polished 320grit silicon carbide+US cleaning 3min+abraded 4s with Cojet Sand
Hand-polished 320grit silicon carbide+US cleaning 3min+abraded 4s with Cojet Sand+Silanization
Hand-polished 320grit silicon carbide+US cleaning 3min+roughened 4s with fine grit diamond bur+32% H3PO4 15s
Hand-polished 320grit silicon carbide+US cleaning 3min+roughened 4s with fine grit diamond bur+32% H3PO4 15s+Silanization
Jet prophylaxis+Sodium bicarbonate
Jet prophylaxis+Sodium bicarbonate+Bonding
Jet prophylaxis+Sodium bicarbonate+Silanisation
No treatment
No treatment+abraded with polyester strip
No treatment+abraded without polyester strip
Non air-inhibition+Mylar Strip
Polishing 600grit+Bonding
Polymerization against Mylar Strip+Bonding
Polyester strip+Bonding
Polymerization against Mylar Strip+No treatment

Polymerization against Mylar Strip+Silicacoating 30µm Alumina+Silanization+Bonding
Received two 1mm deep grooves+Etching 35% PA (30s)+Bonding
Rinsed with warm water+brushed with toothbrush 20x
Rinsed with warm water+brushed with toothbrush 20x+99% acetone
Rinsed with warm water+brushed with toothbrush 20x+bracket primer
Rinsed with warm water+brushed with toothbrush 20x+catalyst resin
Rinsed with warm water+brushed with toothbrush 20x+roughening with green stone bur
Rinsed with warm water+brushed with toothbrush 20x+universal resin
Sandblasting 50µm Al_2O_3
Sandblasting 50µm Al_2O_3+Bonding
Sandblasting 50µm Al_2O_3+Cleaning 35% H3PO4(30s)
Sandblasting 50µm Al_2O_3+Cleaning 35% H3PO4(30s)+Bonding
Sandblasting 50µm Al_2O_3+Cleaning 35% H3PO4(30s)+Silanization
Sandblasting 50µm Al_2O_3+Cleaning 35% H3PO4(30s)+Silanization+Bonding
Sandblasting 50µm Al_2O_3+Cleaning 37% H3PO4 (30s)+Bonding
Sandblasting 50µm Al_2O_3+Etching 35% H3PO4(30s)+Silanisation+air syringe 23°C
Sandblasting 50µm Al_2O_3+Etching 35% H3PO4(30s)+Silanisation+blowdrier 38°C
Sandblasting 50µm Al_2O_3+Etching 35% H3PO4(30s)+Silanisation+Bonding+air syringe 23°C
Sandblasting 50µm Al_2O_3+Etching 35% H3PO4(30s)+Silanisation+Bonding+blowdrier 38°C
Sandblasting 50µm Al_2O_3+Etching 37% H3PO4(30s)+Bonding+light curing in air-atmosphere
Sandblasting 50µm Al_2O_3+Etching 37% H3PO4(30s)+Bonding+light curing in nitrogen-atmosphere
Sandblasting 50µm Al_2O_3+Silanisation
Sandblasting SB particles (15s)+Bonding
Silanization+Bonding
Silicon Carbide bur 140grit
Silicon Carbide bur 140grit+Bonding
Wet-grinding 1200grit+Bonding
Wet-grinding 1200grit+CoJet Sand+Silanization+Bonding
Wet-grinding 1200grit+Silanization+Bonding
Wet-grinding 320grit
Wet-grinding 320grit+Bonding

Table 4 Descriptive statistics on the different parameters tabulated from the selected studies according to the surfac conditioning method, aging conditions for the substrate and the test method.

		Value Label	N (Substrate= Adherent)	N (Substrate≠Adherent)
Surface Conditioning	0	Control	28	2
	1	Physical	19	13
	2	Chemical	45	16
	3	Physicochemical	225	101
Test Method	1	Macroshear	213	87
	2	Macrotensile	6	39
	3	Microtensile	98	6
Thermocycling	0	No	257	108
	1	Yes	60	24

		Value Label	N (Substrate= Adherent)	N (Substrate≠Adherent)
Surface Conditioning	0	Control	28	2
	1	Physical	19	13
	2	Chemical	45	16
	3	Physicochemical	225	101
Test Method	1	Macroshear	213	87
	2	Macrotensile	6	39
	3	Microtensile	98	6
Water Storage of the substrate	0	No	129	8
	1	Yes	188	124

Tables 5a-b Significant effects of surface conditioning methods, test methods and their interactions on mean bond strengths for thermocycled groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Table 5a

Tests of Between-Subjects Effects[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	34170.699[a]	13	2628.515	10.640	.000
Intercept	22302.025	1	22302.025	90.276	.000
Surface Conditioning	2871.745	3	957.248	3.875	.010
Test method	2130.357	2	1065.178	4.312	.014
Thermocycling	276.490	1	276.490	1.119	.291
Surface Conditioning * Test method	862.431	3	287.477	1.164	.324
Surface Conditioning * Thermocycling	761.588	3	253.863	1.028	.381
Test method * Thermocycling	3016.073	1	3016.073	12.209	.001
Surface Conditioning * Test method * Thermocycling	.000	0	.	.	.
Error	74853.616	303	247.042		
Total	699491.658	317			
Corrected Total	109024.315	316			

a. R Squared = .313 (Adjusted R Squared = .284)
b. Substrate=Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Table 5b

Tests of Between-Subjects Effects[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13746.134[a]	11	1249.649	5.941	.000
Intercept	14967.681	1	14967.681	71.153	.000
Surface Conditioning	15.216	3	5.072	.024	.995
Test method	7638.742	2	3819.371	18.156	.000
Thermocycling	326.111	1	326.111	1.550	.216
Surface Conditioning * Test method	2883.175	2	1441.588	6.853	.002
Surface Conditioning * Thermocycling	34.050	3	11.350	.054	.983
Test method * Thermocycling	.000	0	.	.	.
Surface Conditioning * Test method * Thermocycling	.000	0	.	.	.
Error	25243.258	120	210.360		
Total	220211.992	132			
Corrected Total	38989.392	131			

a. R Squared = .353 (Adjusted R Squared = .293)
b. Substrate≠Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Tables 6a-b Significant differences for cross-comparisons and interactions between surface conditioning methods, test methods for thermocycled groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Table 6a

Parameter Estimates[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	36.627	2.871	12.756	.000	30.977	42.277
[Surface Conditioning=0]	-19.670	12.892	-1.526	.128	-45.038	5.699
[Surface Conditioning=1]	5.382	15.241	.353	.724	-24.609	35.373
[Surface Conditioning=2]	-.481	10.117	-.048	.962	-20.390	19.429
[Surface Conditioning=3]	0[a]	-	-	-	-	-
[Test method=1]	-18.378	3.800	-4.836	.000	-25.857	-10.899
[Test method=2]	-16.380	7.295	-2.245	.025	-30.736	-2.025
[Test method=3]	0[a]	-	-	-	-	-
[Thermocycling=0]	.820	3.063	.268	.789	-5.207	6.847
[Thermocycling=1]	0[a]	-	-	-	-	-
[Surface Conditioning=0] * [Test method=1]	13.833	9.055	1.528	.128	-3.986	31.651
[Surface Conditioning=1] * [Test method=1]	-6.145	11.456	-.536	.592	-28.688	16.397
[Surface Conditioning=2] * [Test method=1]	-3.586	4.286	-.837	.403	-12.020	4.847
[Surface Conditioning=0] * [Thermocycling=0]	-5.078	9.756	-.520	.603	-24.276	14.121
[Surface Conditioning=1] * [Thermocycling=0]	-13.115	10.728	-1.222	.222	-34.227	7.997
[Surface Conditioning=2] * [Thermocycling=0]	-12.653	9.756	-1.297	.196	-31.851	6.546
[Test method=1] * [Thermocycling=0]	14.363	4.111	3.494	.001	6.274	22.452
[Test method=1] * [Thermocycling=1]	0[a]	-	-	-	-	-

a. This parameter is set to zero because it is redundant.
b. Substrate=Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Table 6b

Parameter Estimates[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	27.003	5.145	5.248	.000	16.816	37.190
[Surface Conditioning=0]	-10.426	22.003	-.474	.636	-53.990	33.138
[Surface Conditioning=1]	11.127	16.372	.680	.498	-21.289	43.544
[Surface Conditioning=2]	14.334	11.367	1.261	.210	-8.172	36.840
[Surface Conditioning=3]	0[a]	-	-	-	-	-
[Test method=1]	-10.577	3.567	-2.965	.004	-17.640	-3.514
[Test method=2]	-11.830	3.607	-3.280	.001	-18.972	-4.688
[Test method=3]	0[a]	-	-	-	-	-
[Thermocycling=0]	10.083	4.008	2.516	.013	2.148	18.018
[Thermocycling=1]	0[a]	-	-	-	-	-
[Surface Conditioning=1] * [Test method=1]	-20.753	8.134	-2.551	.012	-36.858	-4.649
[Surface Conditioning=1] * [Test method=2]	0[a]	-	-	-	-	-
[Surface Conditioning=2] * [Test method=1]	-22.038	7.950	-2.772	.006	-37.778	-6.298
[Surface Conditioning=2] * [Test method=3]	0[a]	-	-	-	-	-
[Surface Conditioning=0] * [Thermocycling=0]	1.917	24.032	.080	.937	-45.664	49.499
[Surface Conditioning=1] * [Thermocycling=0]	-1.073	15.799	-.068	.946	-32.355	30.208
[Surface Conditioning=2] * [Thermocycling=0]	-3.896	10.072	-.387	.700	-23.838	16.046

a. This parameter is set to zero because it is redundant.
b. Substrate≠Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Tables 7a-b Significant effects of surface conditioning methods, test methods and their interactions on mean bond strengths for water stored groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent)

Table 7a

Tests of Between-Subjects Effects[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	47749.860[a]	15	3183.324	15.638	.000
Intercept	23476.509	1	23476.509	115.324	.000
Surface Conditioning	5996.095	3	1998.698	9.818	.000
Test method	463.494	2	231.747	1.138	.322
Water storage of the substrate	.002	1	.002	.000	.998
Surface Conditioning * Test method	541.298	3	180.433	.886	.448
Surface Conditioning * Water storage of the substrate	853.188	3	284.396	1.397	.244
Test method * Water storage of the substrate	1307.965	1	1307.965	6.425	.012
Surface Conditioning * Test method * Water storage of the substrate	299.325	2	149.663	.735	.480
Error	61274.454	301	203.570		
Total	699491.658	317			
Corrected Total	109024.315	316			

a. R Squared = .438 (Adjusted R Squared = .410)
b. Substrate=Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Table 7b

Tests of Between-Subjects Effects[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	12666.659[a]	9	1407.407	6.523	.000
Intercept	10272.430	1	10272.430	47.610	.000
Surface Conditioning	33.057	3	11.019	.051	.985
Test method	10509.180	2	5254.590	24.354	.000
Water storage of the substrate	108.842	1	108.842	.504	.479
Surface Conditioning * Test method	3795.896	2	1897.948	8.797	.000
Surface Conditioning * Water storage of the substrate	1.018	1	1.018	.005	.945
Test method * Water storage of the substrate	.000	0	.	.	.
Surface Conditioning * Test method * Water storage of the substrate	.000	0	.	.	.
Error	26322.733	122	215.760		
Total	220211.992	132			
Corrected Total	38989.392	131			

a. R Squared = .325 (Adjusted R Squared = .275)
b. Substrate≠Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Tables 8a-b Significant differences for cross-comparisons and interactions between surface conditioning methods, test methods for water stored groups for substrate-adherent type of **a)** being of the same kind (Substrate=Adherent) or **b)** dissimilar (Substrate≠Adherent).

Table 8a

Parameter Estimates[b,c]

Dependent Variable: Mean Bond Strength (MPa)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	38.191	.961	39.734	.000	36.299	40.082
[Surface Conditioning=0]	-22.391	10.774	-2.078	.039	-43.593	-1.189
[Surface Conditioning=1]	-7.733	9.827	-.787	.432	-27.071	11.604
[Surface Conditioning=2]	-13.221	2.476	-5.340	.000	-18.093	-8.349
[Surface Conditioning=3]	0[a]	-	-	-	-	-
[Test method=1]	-18.048	1.737	-10.388	.000	-21.467	-14.629
[Test method=2]	-17.124	6.621	-2.586	.010	-30.154	-4.094
[Test method=3]	0[a]	-	-	-	-	-
[Subtrate aging=0]	-7.734	2.911	-2.656	.008	-13.463	-2.005
[Subtrate aging=1]	0[a]	-	-	-	-	-
[Surface Conditioning=0] * [Test method=1]	20.954	12.090	1.733	.084	-2.838	44.745
[Surface Conditioning=1] * [Test method=1]	4.884	10.493	.465	.642	-15.766	25.534
[Surface Conditioning=2] * [Test method=1]	9.007	4.418	2.039	.042	.313	17.702
[Surface Conditioning=2] * [Test method=3]	0[a]	-	-	-	-	-
[Surface Conditioning=0] * [Water storage of the substrate=0]	1.534	15.453	.099	.921	-28.875	31.943
[Surface Conditioning=1] * [Water storage of the substrate=0]	-8.106	7.943	-1.020	.308	-23.738	7.526
[Surface Conditioning=2] * [Water storage of the substrate=0]	-7.436	11.351	-.655	.513	-29.772	14.901
[Test method=1] * [Water storage of the substrate=0]	26.296	3.483	7.549	.000	19.441	33.151
[Test method=1] * [Water storage of the substrate=1]	0[a]	-	-	-	-	-

[Surface Conditioning=0] * [Test method=1] * [S Water storage of the substrate=0]	-16.484	16.731	-.985	.325	-49.408	16.441
[Surface Conditioning=2] * [Test method=1] * [Water storage of the substrate=0]	-9.747	12.797	-.762	.447	-34.931	15.437

a. This parameter is set to zero because it is redundant.
b. Substrate=Adherent
c. Weighted Least Squares Regression - Weighted by Weight

Table 8b

Parameter Estimates[b,c]

Dependent Variable: Mean Bond Strength (MPa)

					95% Confidence Interval	
Parameter	B	Std. Error	t	Sig.	Lower Bound	Upper Bound
Intercept	37.086	3.268	11.349	.000	30.617	43.554
[Surface Conditioning=0]	-9.710	8.975	-1.082	.281	-27.477	8.057
[Surface Conditioning=1]	10.054	4.349	2.312	.022	1.445	18.663
[Surface Conditioning=2]	10.438	5.336	1.956	.053	-.125	21.001
[Surface Conditioning=3]	0[a]	-	-	-	-	-
[Test method=1]	-11.322	3.599	-3.146	.002	-18.448	-4.197
[Test method=2]	-11.830	3.653	-3.238	.002	-19.062	-4.598
[Test method=3]	0[a]	-	-	-	-	-
[Water storage of the substrate=0]	-6.549	4.592	-1.426	.156	-15.639	2.541
[Surface Conditioning=1] * [Test method=1]	-21.759	7.662	-2.840	.005	-36.927	-6.591
[Surface Conditioning=1] * [Test method=2]	0[a]	-	-	-	-	-
[Surface Conditioning=2] * [Test method=1]	-23.250	7.264	-3.201	.002	-37.630	-8.869
[Surface Conditioning=2] * [Test method=3]	0[a]	-	-	-	-	-
[Surface Conditioning=2] * [Water storage of the substrate=0]	-1.403	20.416	-.069	.945	-41.818	39.013

a. This parameter is set to zero because it is redundant.
b. Substrate≠Adherent
c. Weighted Least Squares Regression - Weighted by Weight

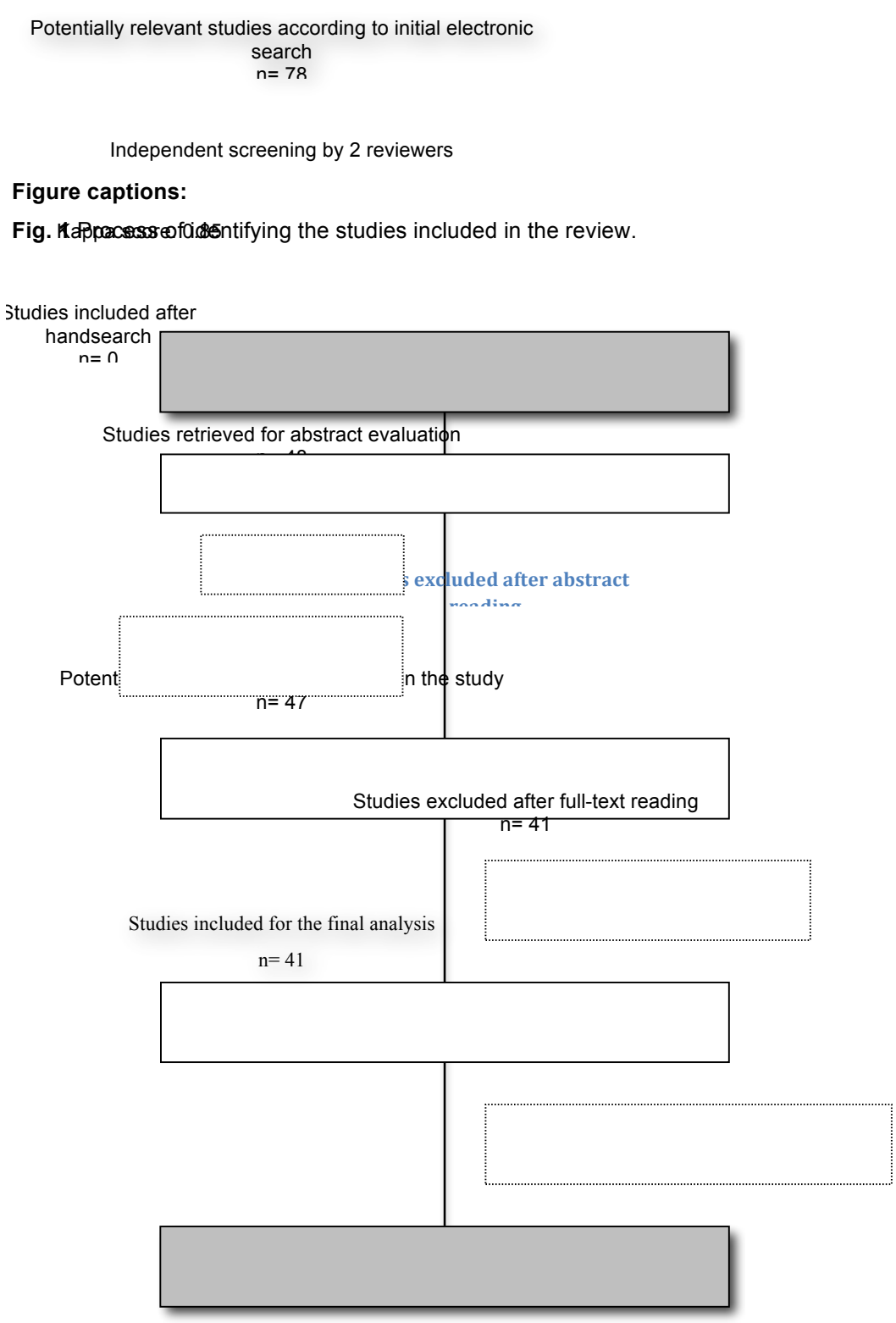
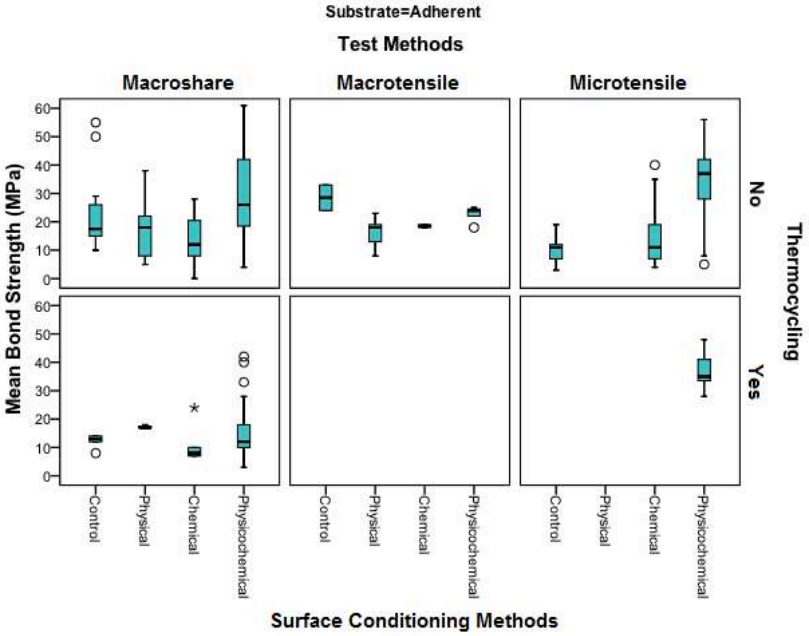


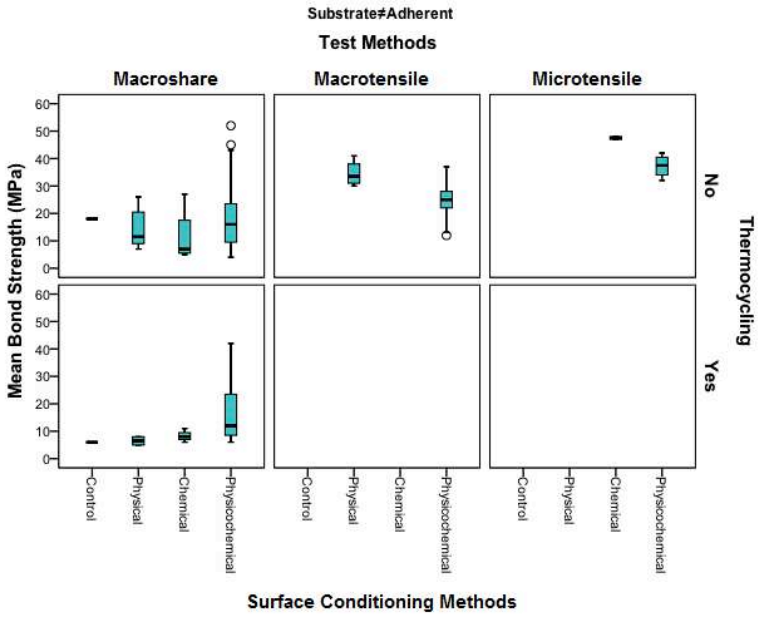
Figure captions:

Fig. 1 Process of identifying the studies included in the review.

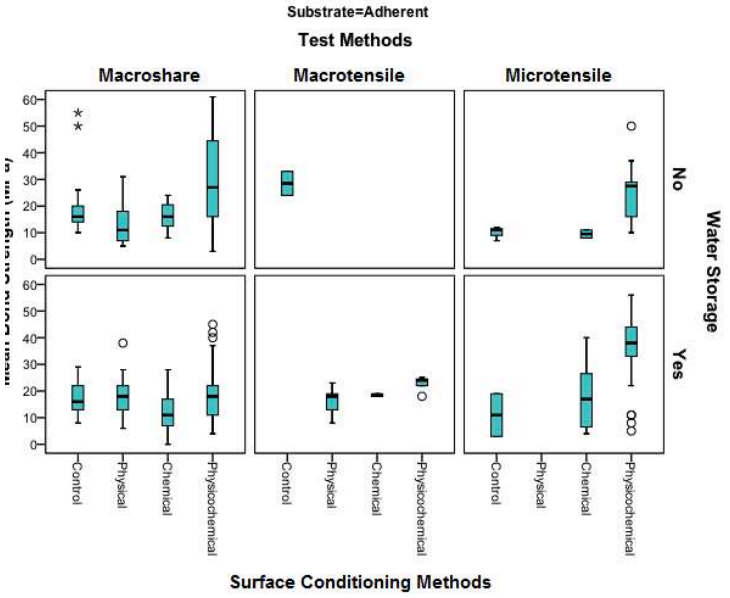
Figs 2a-f Mean bond strength (MPa) for substrate-adherent adhesion of the same kind (Substrate=Adherent) with and without thermocycling of the substrate after macroshear, macrotensile and microtensile tests.



Figs 3a-f Mean bond strength (MPa) for substrate-adherent adhesion of dissimilar composites (Substrate≠Adherent) with and without thermocycling of the substrate after macroshear, macrotensile and microtensile tests.



Figs 4a-f Mean bond strength (MPa) for substrate-adherent adhesion of the same kind (Substrate=Adherent) with and without water storage of the substrate after macroshear, macrotensile and microtensile tests.



Figs. 5a-f Mean bond strength (MPa) for substrate-adherent adhesion of dissimilar composites (Substrate≠Adherent) with and without water storage of the substrate after macroshear, macrotensile and microtensile tests.